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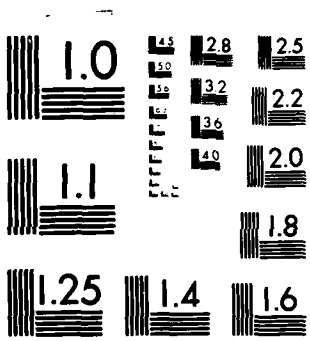
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# AIR FORCE

# HUMAN RESOURCES

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## COMPUTERIZED TECHNOLOGY PACKAGE—ASSET: TEST AND EVALUATION

By

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September 1984

Final Report for Period June 1982 – September 1982

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Results of a limited test and evaluation of ASSET (Acquisition of Supportable Systems Evaluation Technology) are presented. ASSET can be used by system designers and logisticians to consider human resources and other logistics factors in weapon system design during concept development. It consists of six computer models and eight procedures. The models are: Reliability and Maintainability Model; Reliability and Maintainability Cost Model; Training/Aiding Matrix; Page-Estimating Equations; Training Requirements Analysis Model; and Personnel Availability Model. The procedures are: Program Definition Analysis; Consolidated Data Base Development; Maintenance Action Network; Integrated Task Analysis; Logistics Resources Assessment; Comparability Analysis; Life Cycle Cost Assessment; and Design Option Decision Tree. Based on the current investigation, the report recommends use of the Reliability and Maintainability Model, Reliability and Maintainability Cost Model, and Page-Estimating Equations. Of the procedures, the Design Option Decision Tree and the Integrated Task Analysis were recommended. These models and procedures were perceived to meet the minimum requirements of operational readiness for use in a system acquisition program. The other models and procedures, although operational, lack sufficient user-friendly documentation for a novice to gain a full appreciation of their analytical capabilities.


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## PREFACE

The ASSET test and evaluation effort was accomplished under Contract No. F33615-79-C-0030. The contractor was Westinghouse Electric Corporation, Integrated Logistics Support Divisions, Hunt Valley MD 21031. The principal investigator was Gino L. Liberati. The program manager was Richard C. Banta. Westinghouse conducted the independent test and evaluation of the ASSET products developed under previous contract work. A team of contractor personnel conducted the test and evaluation application and provided technical feedback on the strengths and shortcomings of the ASSET package. They were Debra Egber, Jud French, and Ken Whitfield. Air Force personnel assisting in the technical review of this effort included Dr William B. Askren, Col Donald C. Tetmeyer, and Capt Dennis F. Spray.

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## 1.0 INTRODUCTION

### 1.1 The Problem

A need exists for the early consideration of logistics factors during weapon system design. The reason is that significant cost savings can be realized if design changes are made while the design is only on paper or in digital data banks, without need to modify expensive hardware. These savings can be achieved during the conceptual phase of system acquisition when the system operational requirements and maintenance concept are being formulated and evaluated.

If designers have the means to evaluate the impacts of different weapon system designs on logistics factors such as manpower, spares, training, technical order documentation, and facilities, they would select the design that encompasses the best combination of the operational and logistics factors at minimum cost. This is the ideal concept; achieving it in an operational setting is a different matter.

The Air Force Human Resources Laboratory (AFHRL) has been working the problem of early consideration of logistics factors in weapon system design from a variety of perspectives. The Laboratory pioneered the estimation of maintenance manpower requirements for new weapon systems using simulation models such as the Logistics Composite Model. AFHRL developed handbooks on technical order acquisition. It investigated ways to encourage engineers to consider human resources in system design. It developed system ownership costing models for avionics systems and computer programs for assessing the training implications of weapon systems. These products have been applied individually and on a random basis within the system acquisition process. If individual applications could influence weapon system design, their collective application might influence design even more. In 1976, an ambitious project was initiated to establish a mechanism for the coordinated application of these human resources products. The project became known as the Acquisition of Supportable Systems Evaluation Technology (ASSET).

### 1.2 ASSET

ASSET is a technology package consisting of computerized tools and procedures which may be used to evaluate the impacts of weapon system designs on human resources, life cycle cost, training and technical order requirements. ASSET also has the potential for coordinating the development of training programs and technical manuals during weapon system development. ASSET has eight procedures: (a) Program Definition Analysis, (b) Consolidated Data Base Development, (c) Integrated Task Analysis, (d) Maintenance Action Network, (e) Logistics Resources Assessment, (f) Comparability Analysis, (g) Life Cycle Cost Assessment, and (h) Design Option Decision Tree. There are six computer programs: (a) Reliability and Maintainability Model, (b) Reliability and Maintainability Cost Model, (c) Training Requirements Analysis Model, (d) Training/Aiding Matrix, (e) Page Estimating Equations, and (f) Personnel Availability Model. Descriptions of each procedure and tool are presented in Section 3.0.

ASSET was the end product of a four-phased effort that spanned approximately 6 years. The last three phases were designed to build on the achievements of each preceding phase. Phase one was called "The Life Cycle Cost of the C-130E Weapon System." It laid the foundation for constructing a coordinated human resources technology by addressing the development of a data base for use in establishing the support requirements of new systems. It demonstrated the feasibility of obtaining historical system data that could be used in estimating the life cycle costs to be associated with a new but comparable system in design. The case study was the C-130E series (Hercules) aircraft. Five technical reports document the C-130E study (see References 1-5).

Phase two was entitled "The Integration and Application of Human Resource Technologies in Weapon System Design." It established a basis for integrating the technologies of system ownership costing, manpower and personnel estimation, training and technical order requirements into one technology package. The mechanism for coordinating these separate technologies was the consolidated data base concept developed in phase one. Specifications for a consolidated data base were developed in this phase. All of the data elements that ASSET required were to be assembled into one repository. This meant that the techniques for estimating system ownership costing and the maintenance manpower demands of new weapon systems would access data from one location. Furthermore, the data used to generate system ownership costs could be massaged for information on the training and technical order requirements for that system.

During phase two, the Laboratory demonstrated the coordinated technology package and its consolidated data base during the 1977-1979 time frame. The test case was the Advanced Medium Short Take-off and Landing Transport. The government engineers were evaluating various configurations of its avionics and landing gear subsystems and they used components of ASSET to aid them in their evaluations. The transport was to be the ASSET long term test, evaluation and validation vehicle; however the transport program was cancelled in midstream. Efforts to test ASSET were limited to a modest application in phase four. That application is the basis of this report. Nine technical reports document the transport demonstration results and the efforts to integrate the various technologies into one package (see References 6-14).

Phase three was entitled "Maintenance Personnel Availability Analysis." In phase three, the issue of maintenance personnel availability was addressed. The concern over personnel availability came out of research and development (R&D) findings in phase one. During that phase, experienced C-130E operations and maintenance personnel were interviewed about the adequacy of personnel to support the aircraft at various AF bases. Survey results indicated that operational allocations were satisfactory but current maintenance personnel allocations were not. According to the interviews, maintenance personnel were stretched thin to keep squadrons flying. There appeared to be a need for tools to forecast the maintenance personnel requirements of new weapon systems. Therefore, phase three concentrated on ways to accomplish the following objectives: (a) estimate the future availability of maintenance personnel, (b) identify possible difficulties in meeting future weapon system personnel requirements, and (c) examine corrective actions that could alleviate long-run personnel shortages in various job categories. The outcome was a computerized model and an application methodology for tackling the three areas just described. The model was called Personnel Availability Model (PAM). Four technical reports describe the PAM methodology and the R&D that went into its development (see References 15-18).

Phase four, entitled "Test and Evaluation of Technology for Acquiring Supportable Systems," was the last phase and is the subject of this report. It was labeled the test and evaluation sequence because it had two purposes: (a) to determine ASSET's operational readiness for field use, and (b) to evaluate its ability to consider human resources in weapon system design. Although it was intuitively regarded that human resources and other logistics considerations (spares, training, technical manuals, etc.) could be actively considered in system design during the conceptual phase, there was no consensus within the Laboratory that ASSET was the valid means. The previous attempt to test-run ASSET upon a system was precluded. The transport program, mentioned previously, was cancelled before ASSET could be demonstrated fully and its outputs verified against real system data. The next section describes the experimental design for the phase four study.

# 2.0 TEST AND EVALUATION DESIGN

## 2.1 The Hypothesis

The hypothesis behind ASSET was: that it provided the logistics community, design engineers, logistics engineers, and manpower, personnel, and training specialists with effective tools to inject supportability considerations into weapon system design during the conceptual design phase. This injection function was realized through the evaluation and selection of alternative design options. ASSET was assumed to have great power in evaluating alternative design impacts on the human resources and other logistics considerations.

The objective of the test was to determine if ASSET could be used to influence weapon system design.

## 2.2 The Test Bed and Application Technique

For the test bed, the Laboratory selected the APG-66 radar used in tactical aircraft such as the F-16. The radar was selected for the following reasons:

1. Expediency - The contractor selected to conduct the test and evaluation had built the radar and had access to its data.

2. Relevancy - The ASSET package was best suited for avionics applications since some of its components were from avionics data.

3. Research Opportunity - The radar presented an alternative design problem.

The radar had undergone a reconfiguration. The basic radar consisted of three subsystems and six line replaceable units (LRUs). The improved version had three subsystems but only five LRUs. The main difference was the computer. It was packaged differently; instead of a digital signal processor, it now was a programmable one. Figure 1 displays both radar configurations.

ASSET would be used to investigate the impacts of each alternative radar configuration on such logistics considerations as reliability, maintainability, technical orders, and training requirements. Although this application would be purely academic since the improved radar configuration had already been selected and was well into full-scale production, this after-the-fact design problem presented a unique opportunity to try out the ASSET components in order to evaluate how well or how poorly it could assess the logistics implications of system designs. The test was to last 1 month.

The same team of contractors responsible for the conduct of the test and evaluation contract effort would also apply ASSET to the radar configurations. They were logistics engineers knowledgeable in integrated logistics support modeling techniques.

The application technique was purposely left open-ended. The logistics engineers were instructed to apply ASSET given an ASSET users manual and the computerized techniques accessible on the computer facility at Wright-Patterson AFB. The contractors were to approach the ASSET test and evaluation as novices, expecting the ASSET package and its documentation to provide the bootstrap capability for implementing the package or any of its components. Data collection procedures were also left vague. The contractors were to collect the data required to build the ASSET data base. The data collection effort was confined to the contractor's in-house sources.

## 2.3 The Evaluation Criteria and Assessment Scheme

The logistics engineers were to evaluate each ASSET component against four criteria. These criteria were designed to measure ASSET's operational readiness and its efficacy:

1. Criterion No. 1: Can the ASSET component contribute logistical information critical to the selection of one design option over another?

2. Criterion No. 2: Is the ASSET component well defined? If the component is a procedure, does it contain specific instructions to conduct the analysis? If a component is a computerized technique, are the data elements sufficiently well-defined to preclude any confusion over their meanings?

3. Criterion No. 3: Are the theoretical assumptions explicit and do they make intuitive sense to a logistics engineer?

4. Criterion No. 4: Is the component's documentation complete and clear such that outside application advice can be kept to a minimum?

No rating scheme was developed to rate ASSET's components. The logistics engineers would subjectively assess ASSET by each criterion. Their remarks would indicate if the component was adequate or deficient in meeting each criterion. These narrative assessments would provide more insight into each evaluation criterion than would a numerical rating scheme.

The thrust of this effort was to test and evaluate ASSET and not two radar design configurations. Test results for both radar configurations are used for illustrative purposes only in this report and carry no significance outside of this specific demonstration.

Before delving into the test application, it might prove beneficial for the reader to become familiar with the hypothesized application of ASSET to a weapon system design. Section 3.0 presents a typical ASSET application.

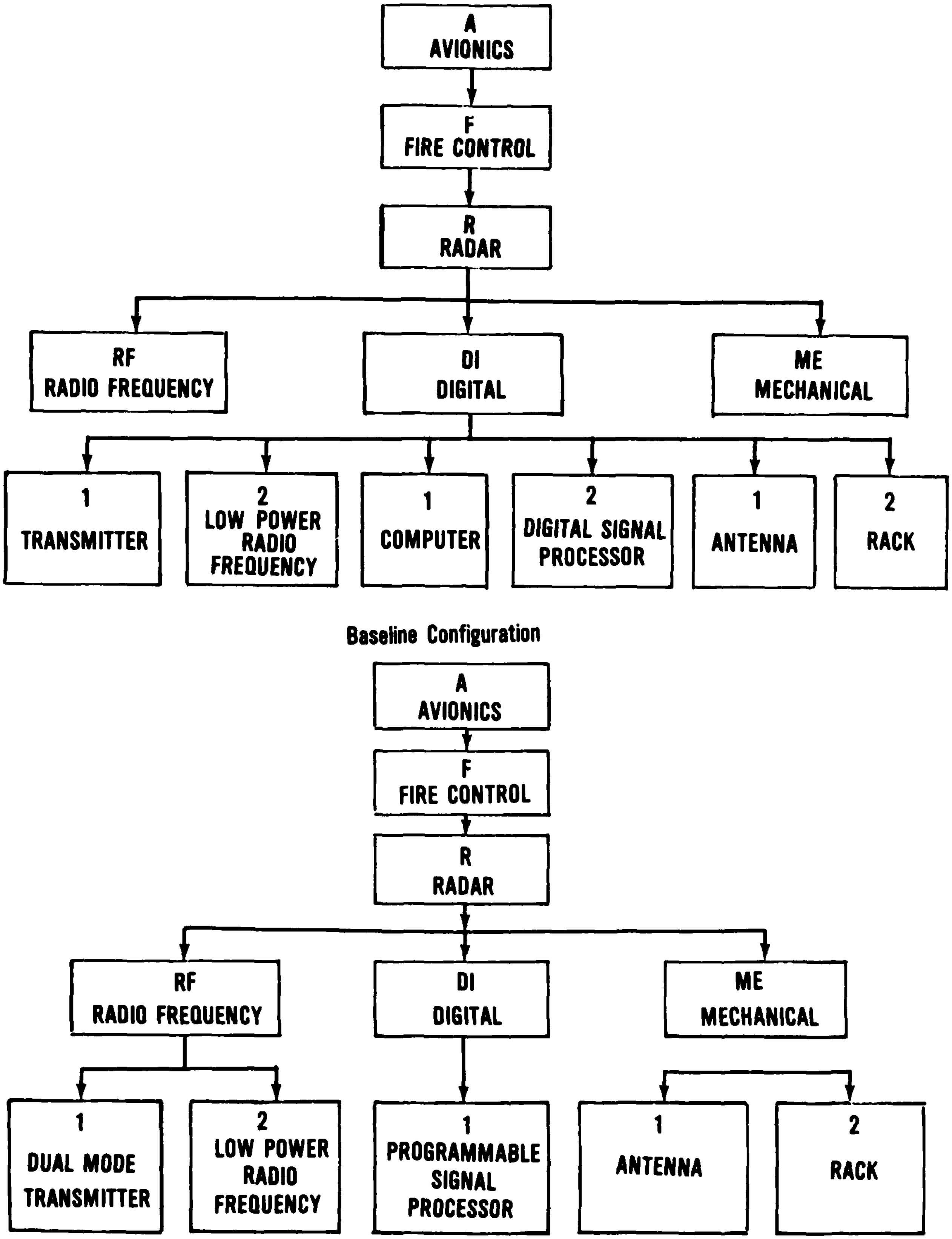



Figure 1. Equipment hierarchies for radar designs.

## 3.0 TYPICAL ASSET APPLICATION

Figure 2 displays at a glance how an ASSET application is conceptualized. An ASSET application starts with the Program Definition Analysis. Through this process, the scope and goals of the particular application are set. Decisions as to which procedures and models to use are also made. For example, if the purpose was to evaluate the life cycle cost implications of a design, the Life Cycle Cost Assessment procedure and its associated technique, the Reliability and Maintainability Cost Model, would be used. The ASSET user must learn as much about the proposed weapon system as possible including its system and mission requirements, maintenance concept, and physical characteristics.

Once the scope and goals are determined, the consolidated data base is developed. Acquisition of the right type of input data in a timely manner and the presentation of these data in a manageable format are important parts of the data base concept. The data base stores all the data that the models and procedures need. (Figure 3 depicts the data categories.) Data are stored in both hard-copy form and software files. The data base will also store the data generated by the various models. The user must use ingenuity in locating and obtaining data to build a consolidated data base. Portions of the data base may be established immediately if values for data elements are available; some data may be derived from other ASSET procedures, such as the Integrated Task Analysis and the Maintenance Action Network.

ASSET requires task analysis data specific to the proposed design. This task analysis is developed using the Integrated Task Analysis procedure in conjunction with the Maintenance Action Network procedure. The task analysis is driven by data requirements for the maintenance action network.

For example, the user must provide task data for up to seven types of flightline maintenance events and three types of shop-related maintenance events for each piece of equipment. The user must also identify the maintenance personnel by Air Force Specialty Code (AFSC) and skill level and the must identify support equipment required to perform the maintenance events. These maintenance events are pegged to the generic Maintenance Action Network which serves as the ASSET operating foundation.

An explanation of the data requirements of the Maintenance Action Network should help clarify the limited scope of the Integrated Task Analysis. The network represents a generalized maintenance concept for a weapon system consisting of flightline, and shop repair levels. The purpose of the network is to generate the reliability and maintainability parameter values to be associated with the new system design. The reliability and maintainability factors critically influence other logistical considerations. In addition, the network also aids the task analysis data collection. ASSET uses a tree network as depicted in Figure 4. The network is composed of seven generic flightline events. Depot events are not considered explicitly. This maintenance action network always consists of seven flightline and three shop events. This network is considered adequate

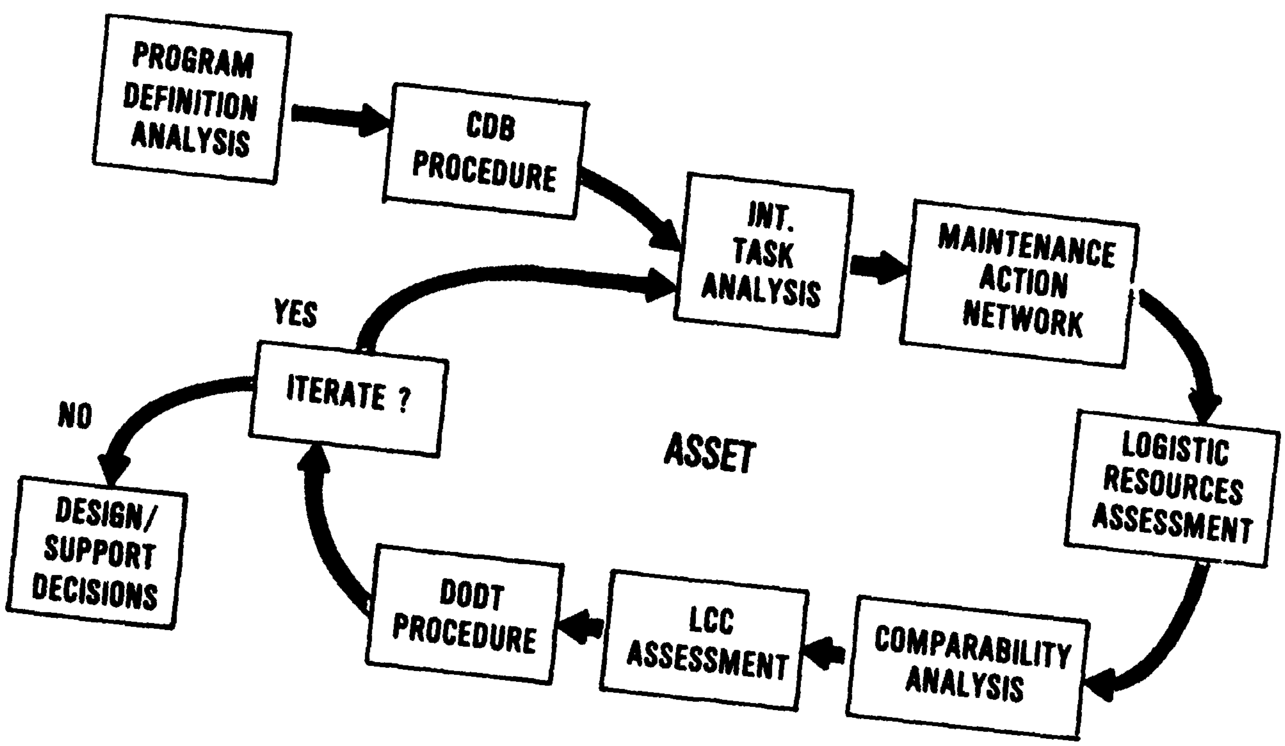
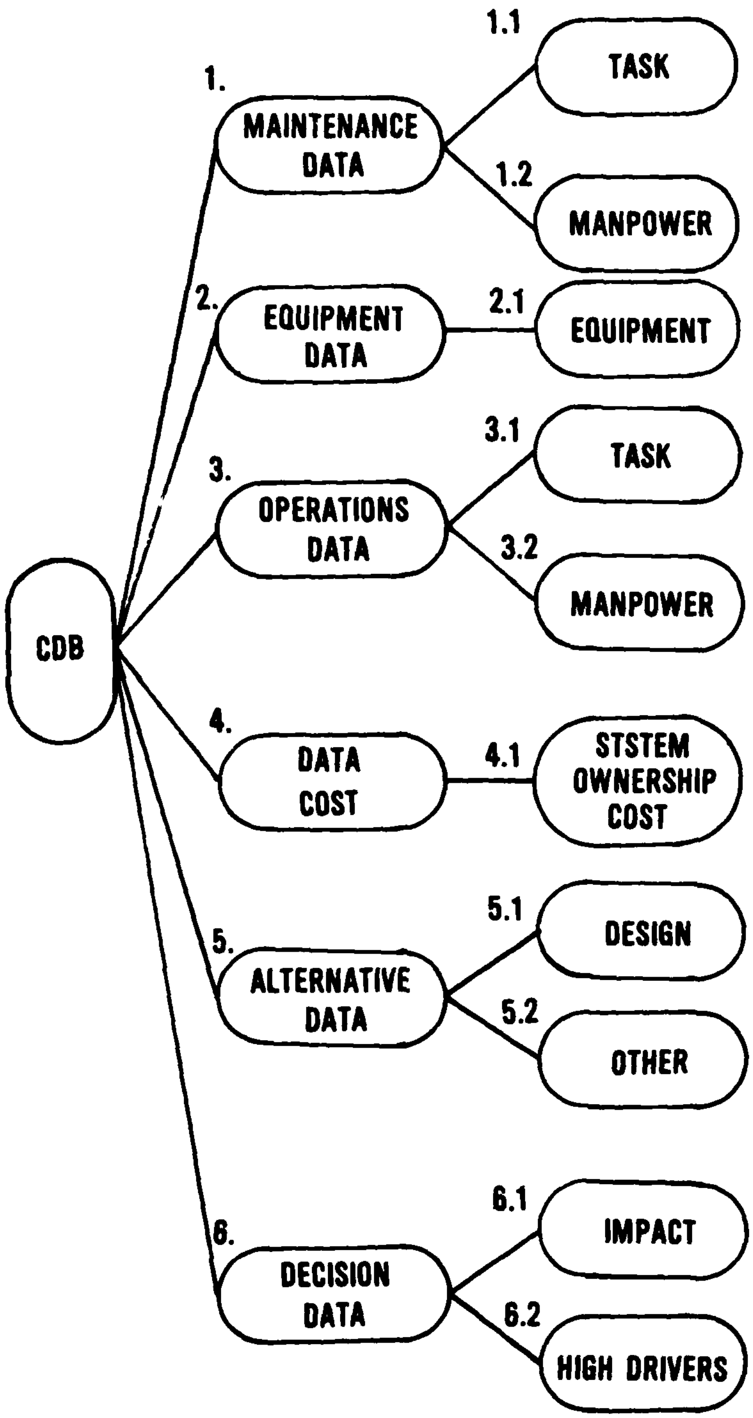



Figure 2. Concept of an ASSET Application.




1.1.1 Maintenance Event Matrix
1.1.2 Maintenance Activity Matrix
1.1.3 Task/condition Matrix
1.1.4 General Task Matrix
1.1.5 Detailed Task List

1.2.1 Manpower Requirements List
1.2.2 Personnel Availability Matrix
1.2.3 ISD/JGD Scope & Magnitude List

2.1.1 Equipment List
2.1.2 R List
2.1.3 list
2.1.4 On-Equipment Data (Maintenance)
2.1.5 On-Equipment Data (Operations)

3.1.1 Operations Task List
3.1.2 Task/Condition Matrix
3.1.3 General Task List
3.1.4 Detailed Task List

3.2.1 Manpower Requirements
3.2.2 Personnel Availibility Matrix
3.2.3 ISD/JGD Scope & Magnitude List

4.1.1 SOC Model
4.1.2 Standard SOC Factor List
4.1.3 Unique SOC Factor List

5.1.1 DODTs

4.2.1 Maintenance/Operations/Support Alternative List

6.1.1 HR Parameters Matrix
6.1.2 SOC Estimate Matrix

SUBGROUP
6.2.1 HR Parameters List
6.2.1 SOC Estimate List FILE

Figure 3. Consolidated Data Base (CDB) components.

for representing a basic maintenance concept for a weapon system. The network may be kept as a hard-copy file in addition to the computer-based data files.

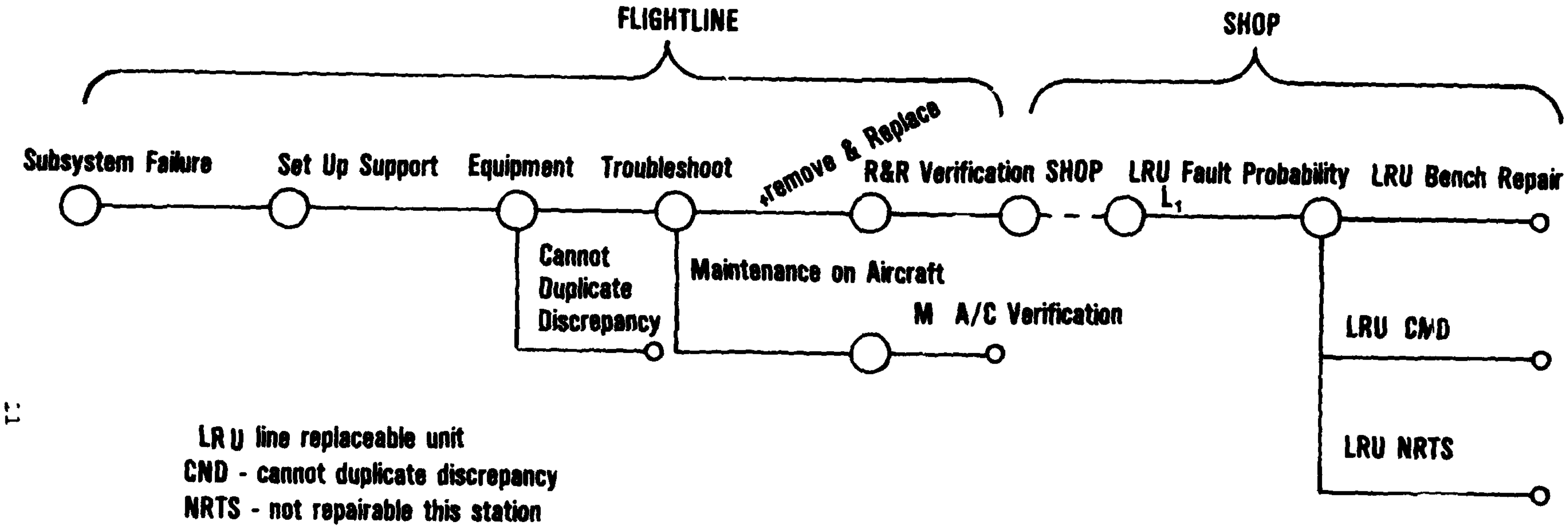
Once the maintenance action network is established, the user moves into the Logistics Resources Assessment Procedure. Through this procedure, the logistics and human resources required by the weapon system are identified and investigated. These resources include such items as support equipment, technical manuals, spares, maintenance personnel, facilities and training. The burden of investigation rests with the user, as this procedure requires that the user investigate and determine the supportablity resource needs under the proposed support concept. During the Logistics Resources Assessment Procedure, one may invoke several or all six of the techniques to help assess the logistics support of the system design. For example, the page-estimating relationships PAGES can be used to help estimate the content and quantity of technical order documentation to support the system.

The next step is the Comparability Analysis procedure. The comparability analysis involves identifying similar equipment to use as a basis for forecasting the resource requirements of the new system. For example, the failure rate data associated with a similar baseline system can be used if those values are adjusted to reflect the different characteristics of the new system. Similarly, the user may invoke the Comparability Analysis procedure to obtain a variety of data for the new system, such as maintainability parameter values and system ownership cost values to support the ASSET evaluations.

After the Comparability Analysis procedure, the user would access the Life Cycle Cost Assessment procedure. Through this procedure, the life cycle cost impact of alternative system designs may be evaluated. This procedure uses the Reliability and Maintainability Cost Model the ASSET life cycle cost model, to evaluate the economic costs of the system design over its expected life time. This procedure promotes understanding of the relationships among system performance, reliability, maintainability, life expectancy and cost of complex systems.

The final procedure is the Design Option Decision Tree. The decision tree illustrates the various alternative design decisions as depicted in the sample in Figure 5. One can annotate the decision tree with life cycle costs, reliability and maintainability values, and all other data derived from the analyses. The decision tree allows one to view at a glance which alternative may pose the best solution to the engineer's design problem.

The set of steps just described above depict the concept application of ASSET. The next section describes the operational application of ASSET to two radar hardware configurations and the results obtained.




LR U line replaceable unit
CND - cannot duplicate discrepancy
NRTS - not repairable this station
R&H - remove and replace
M A/C - maintenance on aircraft

Figure 4. Generalized maintenance action network.

# 4.0 RESULTS

Results of the test and evaluation sequence are organized in the following manner. First, a synopsis is presented of the radar test application. This is followed by the criteria assessments of each ASSET component. The first component tested and evaluated was the Program Definition Analysis.

## 4.1 The Procedures

### Program Definition Analysis

Radar Test Synopsis: In order to place the radar system into a context for ASSET application, the logistics engineers had to invoke the Program Definition Analysis procedure. In this procedure, the engineers had to define their radar system, and they had to determine what their analyses objectives were. To define their radar system, they had to develop a general physical description of the system, i.e., how many subsystems, line replaceable units, and shop replaceable units it had; its operational requirements; its maintenance concept definition; its estimated reliability and maintainability parameter values; its test equipment, maintenance manpower, and skill level-requirements. The engineers obtained data from in-house sources.

The engineers also determined their analysis goals. They were interested in evaluating the reliability and maintainability of the two radar configurations, their life cycle costs, and the training and technical order implications of both configurations. They selected the following procedures and techniques to assist them in their analyses: (a) Consolidated Data Base Development, (b) Integrated Task Analysis, (c) Maintenance Action Network, (d) Logistics Resources Assessment, (e) Comparability Analysis, (f) Life Cycle Cost Assessment, and (g) Design Option Decision Tree procedures. They selected the Reliability and Maintainability Model, the Reliability and Maintainability Cost Model, Page-Estimating Equations and Training/Aiding Matrix for the techniques. The Personnel Availability Model and the Training Requirements Analysis Model were not selected because of known technical difficulties. (These are discussed later in the report.)

### The Assessment:

The engineers could not evaluate the Program Definition Analysis because it is more a process than a procedure. A procedure should contain a sequence of clearly delineated steps for doing an analysis in order to obtain a result. This program definition procedure does not contain a sequence of steps, but merely provides guidelines for encouraging the R&D for a weapon system design. How individual engineers conduct this R&D and what areas they investigate are left to their own devices. However, the logistics engineers thought the intent of the program definition analysis was important; i.e., the logistics engineer should know as much as possible

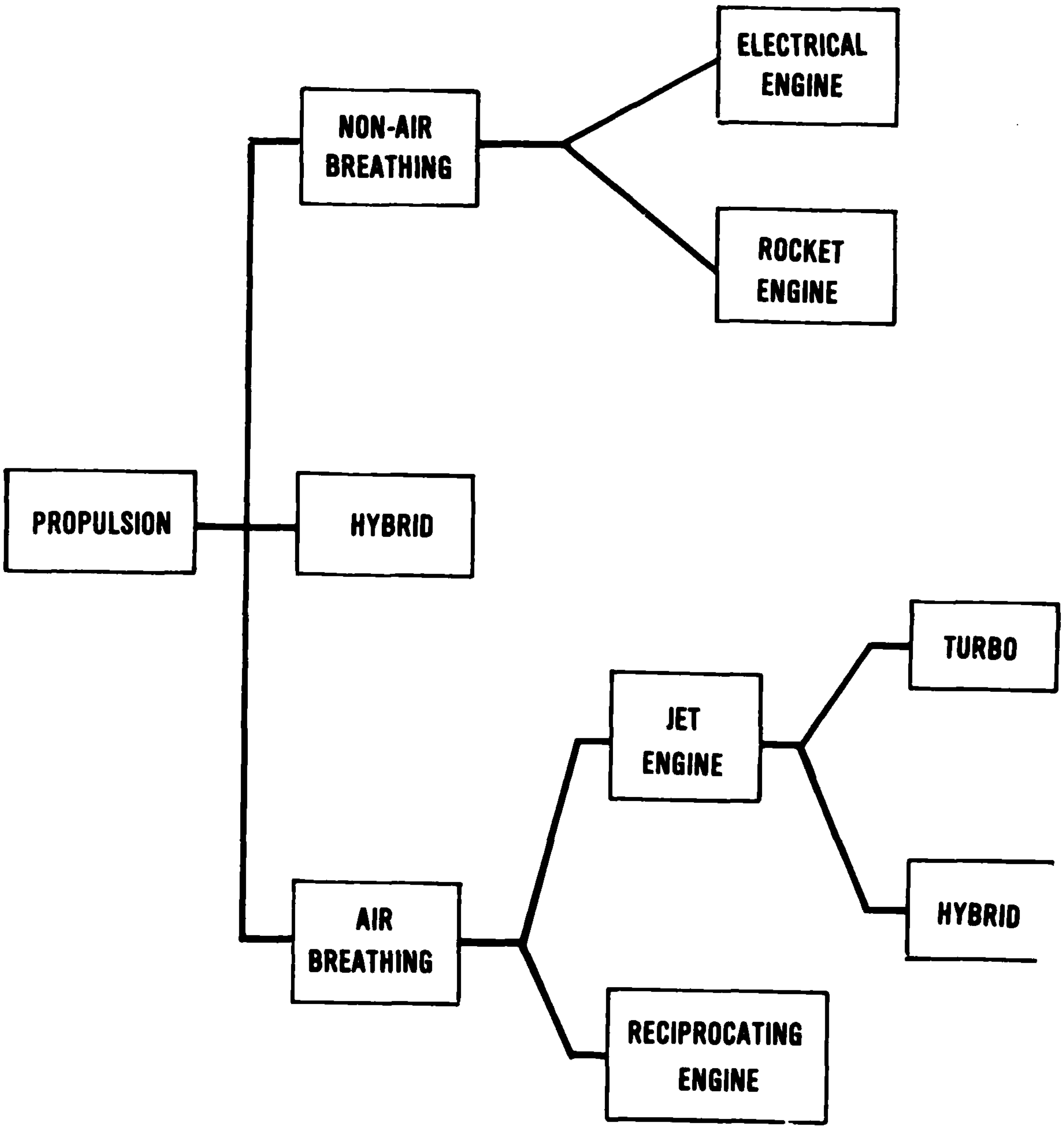



Figure 5. Sample Design Option Decision Tree

about the weapon system program and its potential impacts on a myriad of logistics considerations. Consult Reference 11 for additional information on the procedure.

Consolidated Data Base Development

Radar Test Synopsis: The logistics engineers built their consolidated data base to support the evaluation of the radar system. They required a variety of data such as reliability and maintainability data, system ownership cost data, maintenance event task times, and equipment complexity data (such as the number of subsystems, line replaceable units and shop replaceable units) for the radar's baseline and improved configuration. They obtained their data from a variety of engineers in-house and in a variety of formats; some data existed in hard-copy form; some data existed as engineering best-guesses.

The Assessment:

The consolidated data base was evaluated directly against Criterion No. 2, (How well is it defined?) and indirectly against the other criteria through the ASSET model evaluations. It was reasoned that the model assessments would reflect the sufficiency of the consolidated data base.

Criterion No. 2 - Are the data base data elements well defined so as to preclude any confusion over their meanings?

To evaluate Criterion No. 2, the data base data elements were evaluated in two ways. First, they were evaluated against the Military Standard (MIL-STD) 1388, which governs logistics support analysis (LSA) and its Logistic Support Analysis Records (LSAR) that document the LSA data. Second, the data elements were reviewed for their sufficiency to analyze a system design from a variety of perspectives.

The logistics engineers noted that the CDB and the LSAR share some similarity. Approximately 30 percent of data elements are also specified in the LSAR. The majority of the data element similarities appear on the following LSAR sheets: Data Sheet B, Item Reliability and Maintainability Characteristics; Data Sheet B2, Criticality and Maintainability Analysis; Data Sheet D, Operation and Maintenance Tasks Analysis, and Data Sheet D1, Personnel and Support Requirements. The major difficulty noted was that the data base data element formats are not compatible with LSAR formats. LSAR data sheets cannot be directly loaded into the consolidated data base data element files without some manipulation.

Regarding data elements' sufficiency, the data base data requirements seemed to cover a wide range of logistics considerations. (See Figure 3 for the domain of subject categories.) The major concern was the potential nonavailability of the logistics data during the conceptual phase of system acquisition. It was assumed that a user would input best-estimate data until hard data became available. This soft data would constitute adjusted values obtained from comparable systems on which credible data exist. (Reference 8 contains a detailed description of the CDB data specification.)

Integrated Task Analysis

Radar Test Synopsis: The logistics engineers did not conduct a task analysis for the radar configurations because of time limitations. They obtained task analysis data from training specialists and maintenance specialists within their organization. The subject analysis would have taken at least approximately 2 weeks for a demonstration designed for only a month. However, they reviewed the Integrated Task Analysis procedure and prepared an assessment.

The Assessment:

Criterion No. 1 - Can the Integrated Task Analysis contribute logistical information critical to the selection of one design option over another?

The logistics engineers gave high marks to the procedure. They thought that the Integrated Task Analysis could provide information beneficial to a decision maker if the user has access to comparable system data. The ASSET task analysis deviates from traditional maintenance task analysis in that it is oriented more toward defining the requirements of generic maintenance actions than toward the analysis of individual tasks. The word "Integrated" in the title denotes the coordinated development of training courses and technical orders. Traditionally, task analysis and the determination of technical order and training requirements had been considered independently. The ASSET Integrated Task Analysis provides mechanisms for their mutual development. Those mechanisms include the computerized technique called the Training/Aiding Matrix (to be discussed later). In summary, the Integrated Task Analysis procedure provides information that may be valuable in alternative design selection.

Criterion No. 2 - Is the Integrated Task Analysis well defined? Does it contain specific instructions to conduct the analysis?

Existing technical reports (e.g., AFHRL-TR-80-52, Feb 1981) contain sufficient documentation to conduct the Integrated Task Analysis.

Criterion No. 3 - Are the theoretical assumptions explicit and do they make intuitive sense to a logistics engineer?

The major assumption was that one should coordinate the development of technical orders and training to support a weapon system in concert with the identification and analysis of maintenance tasks to be associated with a new weapon system. This assumption received high marks from the logistics engineers.

Criterion No. 4 - Is the Integrated Task Analysis's documentation complete and clear?

The existing users manual contains information on the Integrated Task Analysis; however, a user would have to consult References 8 and 13 to get a full appreciation for the procedure.

## Maintenance Action Network

Radar Test Synopsis: The logistics engineers found the Maintenance Action Network useful in collecting the data. It was especially helpful in the annotation of the probability relationships among the maintenance events. Figure 6 illustrates the network developed for each baseline radar subsystem. The decimal values at each node are the probabilities of each maintenance event occurring for each subsystem of the radar. In addition, each node may be annotated with the AFSC and skill level required to perform the tasks within each maintenance event and the required support equipment. In-depth descriptions of the generalized maintenance action network may be obtained from Reference 24.

## The Assessment:

Criterion No. 1 - Can the Maintenance Action Network provide information critical to the selection of one design option over another?

The logistics engineers gave the network a marginal assessment. It was considered more a data collection technique than a decision aid. The network serves as the operational foundation for several ASSET models, most notably the Reliability and Maintainability Model which calculates reliability and maintainability figures of merit based upon this generic network. The cost model generates its life cycle cost assessments based on this generalized network. The Training/Aiding Matrix derives its task data from it as well.

Criterion No. 2 - Is the Maintenance Action Network well defined? Is enough information presented to construct it?

The data elements are specific. There is sufficient information to construct a network and results can be conveniently formatted for a user to review. The ASSET network does not encourage evaluations of alternative maintenance support concepts which may consist of maintenance events other than the seven flightline and three shoprelated events already in the network. The network can be modified by zeroing-out the appropriate data element fields, but it cannot be expanded to accommodate more network branches.

Criterion No. 3 - Do the theoretical assumptions behind the maintenance action network make sense to a logistics engineer?

The logistics engineers thought that the basic assumption made intuitive sense, up to a point. A generalized network is suitable for a weapon system during the conceptual phase of system acquisition, but as a system design matures, the logistics engineers concluded that the characteristics of its support concepts may not be captured in the ASSET network. In this event, the ASSET evaluations would be rendered useless.

Criterion No. 4 - Is the documentation complete and clear?

The documentation in the users manual is sufficient to develop the generic maintenance action network.

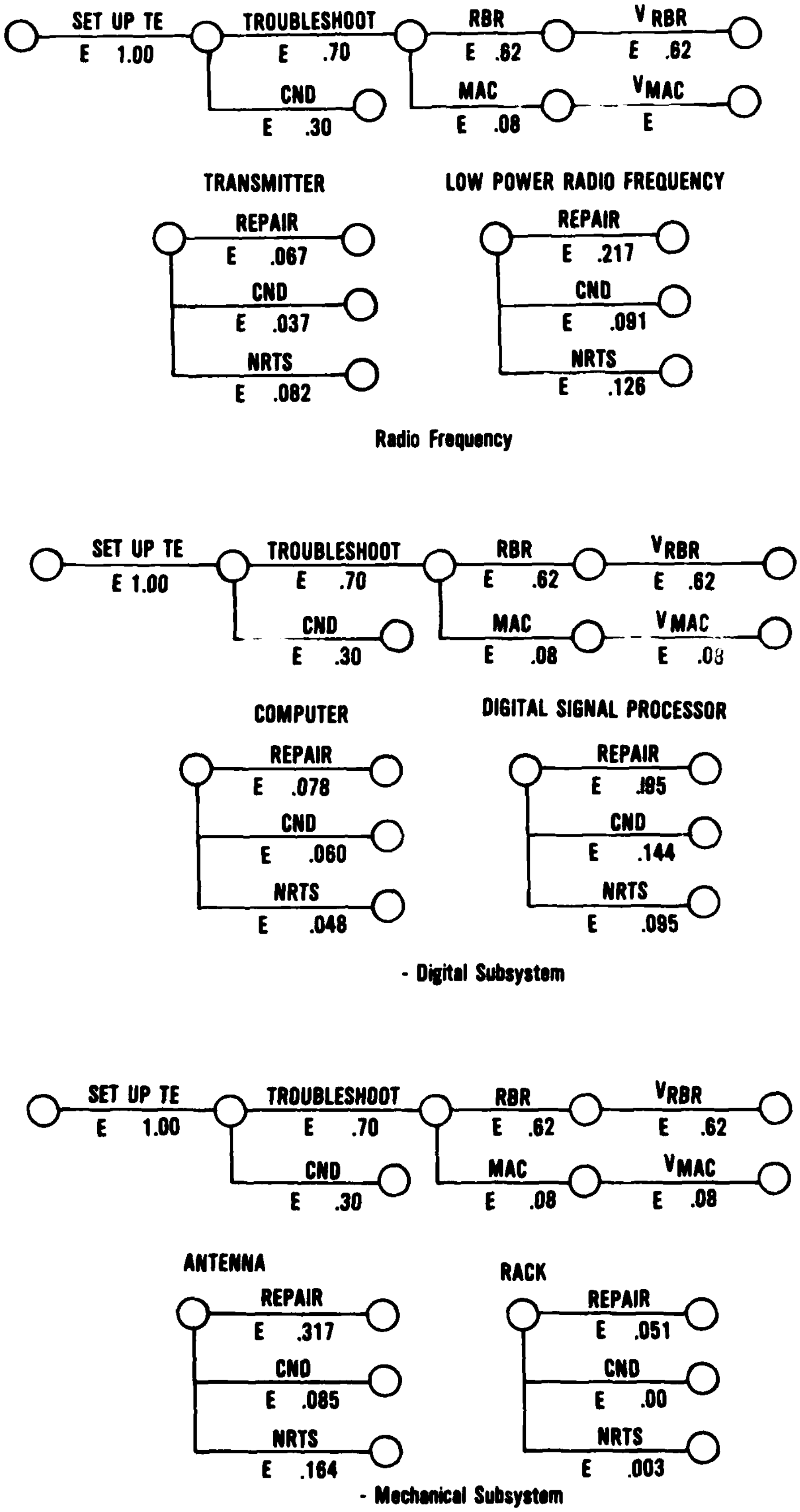



Figure 6. Baseline radar configuration maintenance action networks.

Logistics Resources Assessment

Radar Test Synopsis: This procedure, which is really more a process, encourages the user to apply the ASSET models to identify the logistics and human resources required to support a weapon system configuration. The logistics engineers ran the Reliability and Maintainability Model to calculate the average maintenance manhours, the average maintenance times and the support equipment requirements of the radar configurations. They ran the Reliability and Maintainability Cost Model to obtain life cycle cost values for both versions of the radar system. They ran the Training/Aiding Matrix and the Page-Estimating Equations to assess the training and technical manual implications of the radar configurations. The results of these models provided the engineers with assessments of the logistics requirements for the radar configurations. The results are illustrated in Figure 8 at the end of this section.

The Assessment:

> Criterion No. 1 - Can the Logistics Resources Assessment provide logistical information critical to the selection of one design option over another during the conceptual design phase?

The procedure forces the user to formulate the logistical support considerations of the system design. The procedure calls upon specific resource assessment techniques to establish a logistics resources profile for the design. This profile includes such considerations as manhours, skills, tools, support equipment, spares, training and technical orders, and system ownership cost. In this sense, the procedure can provide useful logistical information.

> Criterion No. 2 - Is the Logistics Resources Assessment well defined? Does it contain specific instructions to conduct a resources assessment of the system design?

The procedure is open-ended and relies on the user to investigate the logistics implications of the design concept. The user may invoke the ASSET tools to aid in the logistics resources assessment analyses. The procedure does not contain specific instructions for conducting a resource assessment.

> Criterion No. 3 - Are the assumptions behind the Logistics Resources Assessment procedure explicit and do they make intuitive sense to a logistics engineer?

The theoretical statements are explicity stated. The theoretical objective is to develop weapon systems that can be supported easily and economically in the field. To obtain this goal, the weapon system design must accommodate as many logistics considerations as possible. The concept of the Logistics Resources Assessment procedure is to inject these considerations into the earliest stage of system development. The logistics engineers considered the concept to be highly commendable.

Criterion No. 4 - Is the Logistics Resources Assessment procedure documentation complete and clear?

Documentation on this procedure is nonexistent. There are no guidelines to apply a resource assessment of a system design other than recommendations for applying the various tools such as the Reliability and Maintainability (RM) Model, Reliability and Maintainability Cost Model, Training/Aiding Matrix, and Page-Estimating Equations.

Comparability Analysis Procedure

Radar Test Synopsis: The logistics engineers simulated the conduct of a comparability analysis. The reason was that they already had an improved hardware radar configuration. In essence, the improved radar configuration and the data to be associated with it were derived from the baseline radar system. The comparability analysis would address the preparation of the new system data. The logistics engineers outlined the steps in their simulated comparability analysis. Specifically, the analysis would be initiated using the baseline radar hardware configuration characteristics as a starting point. The baseline radar maintenance action network and RM model results would help establish the basic reliability and maintainability parameter values for the new system. The comparability analysis would also be extended to address the new system's maintenance tasks and other logistics considerations based on the baseline radar maintenance task and logistical profile. The data parameter values could then be mathematically adjusted by factors to account for the differences between the improved and baseline radar configurations. The adjustment factors could be derived from engineering estimates.

The logistics engineers evaluated the Comparability Analysis procedure even though its application was simulated for the radar.

The Assessment:

Criterion No. 1 - Can the Comparability Analysis procedure provide logistical information critical to the selection of one design option over another during the conceptual phase of system acquisition?

Yes, it can. A comparability study is the overall process used to develop data on newly designed systems by selecting operational equipment similar to that of the proposed weapon system and by adjusting the resource data associated with baseline equipment to reflect the unique characteristics of the new design. The analysis includes the development of maintenance demand rates for the new design which, in turn, can be used to determine resource requirements such as manpower, spares, and support equipment.

Criterion No. 2 - Is the procedure well defined? Does the Comparability Analysis procedure contain enough information to conduct an analysis?

The ASSET users guide does not contain sufficient information. It is assumed that the user has the basic knowledge to do an analysis; the ASSET documentation merely provides recommendations for extending comparability analysis to other logistics factors. At best, the other literature can offer no more than rules-of-thumb for doing an analysis. Consult References 19, 20, and 26 for guidance.

Criterion No. 3 - Are the theoretical assumptions explicit and do they make intuitive sense to a logistics engineer?

Yes, they do. There are two major assumptions. First, a new system design may be developed based on a comparable system in the operational inventory. The majority of current weapon systems are derivatives of older systems incorporating either new or improved operational characteristics. Second, comparability analysis may extend to other logistics considerations such as manpower, spares, training, and technical order requirements from the traditional emphasis on maintenance demand rates.

Criterion No. 4 - Is the Comparability Analysis procedure documentation complete and clear?

The users guide cannot be the sole documentation source for conducting a comparability analysis. The user must refer to other sources, such as indigenous engineering personnel or References 11 and 19 for assistance.

Life Cycle Cost Assessment Procedure

Radar Test Synopsis: The logistics engineers applied the Life Cycle Cost procedure by invoking the Reliability and Maintainability Cost Model. They applied this model to both configurations of the radar system. The logistics engineers did not conduct a cost analysis because of insufficient guidance to conduct the analysis. This deficiency is addressed below. The cost results of the Reliability and Maintainability Cost Model will be presented in the cost model evaluation.

The Assessment:

Criterion No. 1 - Can the Life Cycle Cost Procedure contribute logistical information critical to the selection of one design option over another?

The procedure alone cannot provide critical information. The reasons are contained in the following assessments.

Criterion No. 2 - Is the concept well defined? Does the Life Cycle Cost Assessment procedure contain specific instructions to conduct a cost analysis?

The procedure does not contain sufficient detail to conduct a cost analysis. It is assumed that an individual is aware of the basic steps involved in a cost analysis, such as (a) establish the objective or the standard for accomplishment, (b) identify all feasible alternatives to meet the objective, (c) formulate assumptions about the alternatives being evaluated, (d) determine costs and benefits, (e) compare costs and benefits, and (f) test alternatives under uncertainty. The ASSET procedure implies these procedural steps. The logistics engineers approached the Life Cycle Cost Assessment procedure as novices anticipating guidance to prepare and conduct a cost analysis; however, they found none in this procedure.

Criterion No. 3 - Are the theoretical assumptions behind the Life Cycle Cost Assessment procedure explicit and do they make intuitive sense to a logistics engineer?

This criterion is best addressed during the cost model evaluation. The Reliability and Maintainability Cost Model is the principal tool in this procedure.

Criterion No. 4 - Is the Life Cycle Cost Assessment procedure documentation complete and clear?

Documentation is not sufficient for a user with no working knowledge of cost analysis techniques. The cost model documentation is adequate.

Design Option Decision Tree

Radar Test Synopsis: The logistics engineers prepared a design option decision tree to depict the two design options and the logistics resources assessment of each. The data were derived primarily from the ASSET application. The decision tree is presented at the conclusion of this section in Figure 8 to summarize the findings of the radar test application.

Assessment:

Criterion No. 1 - Can the decision tree contribute logistical information critical to the selection of one design option over another?

The decision tree can provide useful information. It describes system designs by graphically depicting the design options available as the designer progresses through a system design problem. The decision tree facilitates early identification of design options to evaluate appropriate options for impact on human resources, logistics and cost.

It also provides an engineering paper trail for the selection of one design option over another. For example, a designer may subjectively decide to use a design to incorporate a particular component into an assembly with little or no apparent justification. The decision tree captures that rationale or justification by the graphic depiction of the critical charcteristics of each alternative design.

Criterion No. 2 - Is the decision tree procedure well defined? Does it contain specific instructions to construct a design option decision tree?

ASSET documentation is insufficient. However, there are technical reports available that describe the mechanics of the decision tree preparation in sufficient detail. Consult Reference 21 for guidance. The ASSET documentation treats the design option decision tree at a managerial level and does not go into the decision tree mechanics.

Criterion No. 3 - Are the theoretical assumptions behind the Design Option Decision Tree procedure explicit and do they make intuitive sense to a logistics engineer?

The decision tree received high marks. The major assumption is: If the decision tree is deemed a feasible method for describing system design configuration options, and literature on other tests suggests that it is, it may provide a means for the consideration of the human resources and logistics implications of system design. This assumption made intuitive sense to the logistics engineers.

Criterion No. 4 - Is the documentation complete and clear?

The ASSET documentation is not complete. Decision tree definition and intent are clear. Reference 21 should augment the ASSET users guide.

This completes the procedure evaluations. The following section contains the model or technique evaluations.

## 4.2 The Models

### Reliability and Maintainability Model

Programming Language: FORTRAN IV
Core Requirement: 142K
Operation: Batch

General Description: The Reliability and Maintainability Model is used for estimating the average system support resource requirements driven by the reliabilty and maintainbility parameter values to be associated with the system design. The Reliability and Maintainability Model operates on the generic Maintenance Action Network concept to calculate the maintenance resource demands. The model uses three figures of merit to estimate these demands. These figures of merit are (a) MTTR/KFH (mean time to repair per 1,000 flight hours), (b) MMH/KFH (direct maintenance manhours per 1,000 flight hours), and (c) $A_i$ (system inherent availability). The figures of merit, MTTR/KFH and MMH/KFH, are generated for flightline and shop maintenance. Detailed information regarding the Reliability and Maintainability Model may be obtained from Reference 20. Additional sources for the Reliability and Maintainability Model are References 22 and 23.

Radar Test Synopsis: The logistics engineers applied the Reliability and Maintainability Model to both configurations of the radar system.

They obtained figures of merit for each subsystem of each radar configuration. For example, figures of merit were recorded for the radio frequency subsystems, the computer or digital subsystems and the mechanical subsystems for the baseline and improved configurations.

Table 1 shows the flightline figures of merit. The abbreviations, AFRRF, AFRDI, and AFRMK represent the radio frequency, digital, and mechanical subsystems, respectively.

<u>The Assessment</u>:

Criterion No. 1 - Can the Reliability and Maintainability Model contribute logistical information critical to the selection of one design option over another?

The logistics engineers thought that it did contribute information. The Reliability and Maintainability Model can provide estimates for the average maintenance manhours, average repair times, and support equipment needs to be associated with a system or its components. They thought that the figures of merit were useful in identifying suspected high resource consumers. For example, in Table 1 the radio frequency (AFRRF) subsystem for both radar configurations had the highest figures of merit. This indication could spur the engineers to investigate the potential drivers behind the figures of merit.

The Reliability and Maintainability Model can also generate other information such as the average repair time for a component of a system or the average maintenance time per task event per subsystem. The average number of manhours required to support a particular maintenance event may also be obtained from the model. The Reliability and Maintainability Model generates this information in report formats. Detailed descriptions of these reports may be obtained from Reference 20.

Criterion No. 2 - Are the Reliability and Maintainability Model data elements well defined?

The data elements were relatively self-explanatory. The engineers prepared a set of 53 cards each for the baseline and improved radar configurations. The logistics engineers experienced little or no difficulty in providing input values for approximately 41 data elements to operate the Reliability and Maintainability Model. A print-out of the data inputs and data values may be obtained from Reference 20.

The Reliability and Maintainability Model generates batch output from card input. Feedback can occur in as fast as several minutes or as long as an hour, depending on the computer-based traffic. The Reliability and Maintainability Model operates on a mainframe computer at Wright-Patterson AFB.

Criterion No. 3 - Are the theoretical assumptions explicit and do they make intuitive sense to a logistics engineer?

Table 1. Flightline Level FOM-Baseline and Improved Configurations (Identical Results)

| Subsystem | MTTR/KFH | MMH/KFH | $A_i$ |
|---|---|---|---|
| AFRRF | 4.58 | 4.58 | 99.5 |
| AFRDI | 3.40 | 3.40 | 99.6 |
| AFRME | 0.78 | 0.78 | 99.9 |

AFRRF radio frequency

AFRDI computer subsystem

AFRME mechanical subsystem, i.e., antenna,rack.

MMH/KFH (Mean Time to Repair per 1000 flight hours).

MTTR/KFH (Direct Maintenance Man Hours per 1000 flight hours).

$A_i$ (System Inherent Availability).

The major operating assumption is that one can determine the maintenance requirements of a system from an analysis of the figures of merit; namely, Mean Time to Repair per 1000 flight hours and Maintenance Manhours per 1000 flight hours. There is serious concern that one cannot translate maintenance manhours directly into the numbers of maintenance personnel required to support the system once released to the operational inventory. Also, maintenance resources demand may not be adequately estimated by an average value model such as the Reliability and Maintainability Model since it is driven by a generalized support concept. The generalized maintenance action network may be modified by inserting zeroes for data element fields. For example, if a user were interested only in organizational maintenance, the intermediate shop data fields would be zeroed-out. The network may not be manipulated structurally to reflect new maintenance events specific to a new weapon system or new support concept. The logistics engineers concluded that the Reliability and Maintainability Model may be useful as a check against other analyses during conceptual design studies but should not be used as the sole source for maintenance requirements determination.

Criterion No. 4 - Is the Reliability and Maintainability Model documentation complete and clear?

It was determined that the documentation was complete and clear. The users guide, Reference 20, contains all the data input and output requirements for the Reliability and Maintainability Model.

<u>Reliability and Maintainability Cost Model</u>

Programming Language: FORTRAN IV EXTENDED
Core Requirement: 125K
Operation: Interactive and Batch Output Reports

<u>General Description</u>: The Reliability and Maintainability Cost Model is a cost accounting model and a companion to the Reliability and Maintainability Model. It computes recurring, nonrecurring, and disposable costs to be associated with a new weapon system based on the reliability and maintainability values generated by the Reliability and Model. The cost elements are depicted in Figure 7. Portions of the Reliability and Maintainability Cost Model can be adjusted to conduct sensitivity analyses. The Reliability and Maintainability Cost Model generates costs in constant year dollars. The user may input inflation rates and a discount rate to account for the time value of money. Details on the cost model and its operation can be obtained from Reference 20.

<u>Radar Test Synopsis</u>: The Reliability and Maintainability Cost Model was used to study the life cycle cost sensitivity of the two radar configurations to increases in their individual reliability and unit costs. Mean flight hours between maintenance actions (MFHBMA) and unit cost were increased 20%. Tables 2 and 3 summarize the results. The logistics engineers obtained data from in-house sources. The life cycle values were discounted by 10% to reflect the present value of money. Table 2 depicts the life cycle costs for the baseline configuration. The total recurring

- LCC- LIFE CYCLE COST
  - NRC NON-RECURRING COST
    - CRD-COST OF RESEARCH & DEVELOPMENT
    - CSI COST OF SYSTEM INVESTMENT
      - CCP-COST OF PROCUREMENT
      - CPM-COST OF PROJECT MANAGEMENT
    - COI COST OF SUPPORT INVESTMENT
      - CPTI-COST OF INITIAL MAINTENANCE PERSONNEL TRAINING
      - CSPI-COST OF SPARES INVESTMENT
      - CDRI-COST OF INITIAL DEPOT SUPPORT EQUIPMENT
      - CSEI-COST OF BASE LEVEL SUPPORT EQUIPMENT INVESTMENT
      - CSWI-COST OF SOFTWARE ACQUISITION
      - CJGI-COST OF INITIAL MAINTENANCE MANUALS
      - CIMI-COST OF INVENTORY MANAGEMENT INITIAL
      - CFAI-COST OF NEW OR ADDITIONAL FACILITIES
  - RC RECURRING COST
    - CO COST OF OPERATION
      - COP-COST OF OPERATIONS PERSONNEL
      - CFL-COST OF FUEL
    - CS COST OF SUPPORT
      - COM-COST OF ON-EQUIPMENT MAINTENANCE
      - CSM-COST OF INTERMEDIATE SHOP MAINTENANCE
      - CPT-COST OF MAINTENANCE PERSONNEL TRAINING
      - CSP-COST OF REPLACEMENT SPARES
      - CDR-COST OF DEPOT MAINTENANCE
      - CSE-COST OF MAINTAINING SUPPORT EQUIPMENT
      - CSW-COST OF SOFTWARE SUPPORT
      - CJG-COST OF SUPPORTING MAINTENANCE MANUALS
      - CIM-COST OF INVENTORY MANAGEMENT
  - CDP COST OF SYSTEM DISPOSAL

Figure 7. RMCM cost elements.

cost did not change significantly with a 20% increase in reliability. Nonrecurring cost reflected an increase, however, from approximately $33 million to $36 million. The total life cycle cost over an inventory usage period of 14 years increased from approximately $70,000 to $74,000 as a result in the increases in reliability and unit cost. The same held true for the improved configuration. However, the improved radar design incurred higher nonrecurring costs. Total life cycle cost was substantially higher; from approximately $159 million to $172 million. Thus, the total life cycle costs for both radar configurations were higher when reliability and unit cost were increased 20%. Table 4 displays the initial life cycle costs estimates for both radar configurations.

<u>The Assessment</u>:

Criterion No. 1 - Can the Reliability and Maintainability Cost Model contribute logistical information critical to the selection of one design option over another?

Its best contribution is its cost sensitivity analysis feature that car be used to evaluate weapon systems with uncertain design characteristics. The user can make upward or downward adjustments to any number of parameter values such as MTBF or unit cost to analyze the anticipated effects on downstream costs.

Criterion No. 2 - Are the Reliability and Maintainability Cost Model data elements well defined?

The data elements are not fully defined since an indepth data element dictionary does not accompany the model. The data element dictionary that exists gives, at a minimum, the name of the data element and its field format, and sketchy data element descriptions. However, a user can still operate the model and derive some benefits from it, especially from the interactive sensitivity analysis feature.

The majority of the Maintainability Cost Model data elements are derived from cost-estimating relationships. The remainder consist of standard values obtained from Government sources and historical estimates derived from comparable system historical cost experience.

Since the Reliability and Maintainability Cost Model is an interactive program, a decision maker can get almost instantaneous feedback. The Reliability and Maintainability Cost Model can also operate on the Reliability and Maintainability Model data base which precludes data base construction from scratch. The only portion that requires manual loading is the cost data. The logistics engineers prepared approximately 40 data cards bearing cost values to run the cost model for one radar configuration.

Additionally, the cost model provides a computer printout of the reports. Included in these reports are life cycle costs by subsystem and LRU contributions. Consult Reference 20 for further information.

Table 2. Life Cycle Cost - Baseline Configuration for Radar with Three Subsystems/Six LRUs

| Life Cycle Cost Categories | Static | Perturbed (Reliability & Unit Cost Increased 20%) |
|---|---|---|
| **Recurring** | | |
| Support | | |
| Flight Line Maintenance | $ 31,063 | $ 28,237 |
| Shop Maintenance | $ 214,069 | $ 194,596 |
| Depot Maintenance | $ 236,302 | $ 230,497 |
| Spares | $ 342,594 | $ 365,394 |
| Other | $30,777,602 | $30,775,461 |
| Operation | $ 6,024,045 | $ 6,024,045 |
| Subtotal | $37,625,675 | $37,618,230 |
| **Non-Recurring** | | |
| R&D | $ 0 | 0 |
| System Investment | $17,137,162 | $20,074,961 |
| Support Investment | $15,222,745 | $15,968,143 |
| Subtotal | $32,359,907 | $36,043,104 |
| Disposal | $ 0 | 0 |
| TOTAL | $69,985,582 | $73,661,334 |

Table 3. Life Cycle Cost - Improved Configuration (Radar With Three Subsystems/Five LRUs)

| Life Cycle Cost Categories | Static | Perturbed (Reliability & Unit Cost Increased 20%) |
|---|---|---|
| Recurring | | |
| Support | | |
| Flight Line Maintenance | $ 31,062 | $ 28,237 |
| Shop Maintenance | $ 266,258 | $ 242,032 |
| Depot Maintenance | $ 247,380 | $ 240,569 |
| Spares | $ 1,611,104 | $ 1,731,183 |
| Other | $ 41,089,992 | $ 41,088,154 |
| Operation | $ 6,024,045 | $ 6,024,045 |
| Subtotal | $ 49,269,841 | $ 49,354,220 |
| Non-Recurring | | |
| R&D | $ 0 | $ 0 |
| System Investment | $ 56,669,037 | $ 66,383,729 |
| Support Investment | $ 53,055,327 | $ 56,591,531 |
| Subtotal | $ 109,724,364 | $ 122,975,260 |
| Disposal | $ 0 | $ 0 |
| TOTAL | $ 158,994,205 | $172,329,482 |

Table 4. Life Cycle Cost Comparison

| LCC CATEGORIES | Weapon System Radar Configuration | |
|---|---|---|
| | Baseline | Improved |
| Recurring | | |
| Support | $31,601,630 | $43,245,796 |
| Operation | $ 6,024,045 | $ 6,024,045 |
| Subtotal | $37,625,675 | $49,269,841 |
| Non-Recurring | | |
| R&D | $ 0 | $ 0 |
| System Investment | $17,137,162 | $56,669,037 |
| Support Investment | $15,222,745 | $53,055,327 |
| Subtotal | $32,359,907 | $109,724,364 |
| Disposal | $ 0 | $ 0 |
| Total | $69,985,582 | $158,994,205 |

Criterion No. 3 - Are the Reliability and Maintainability Cost Model assumptions explicit and do they make intuitive sense to a logistics engineer?

The assumptions are stated explicitly. The logistics engineers considered the cost model assumptions concerning the general scenario, spares investment, and its cost elements plausible.

For the general scenario, the cost model considers a uniform level of system activity (such as flying hours) at each operating base. The model assumes that air bases are identical with respect to environmental effects on equipment failure rates and logistics support.

With spares investment, the model computes the spares stock level and pipeline quantities to support the peak level of aircraft activity and peak base flying hours rather than any incremental buildups. It is not known if the peak period donates wartime surge. The model assumes that inventories of spare LRUs are located at each of the bases, consistent with the demand rate for replacement parts at the bases.

There are two assumptions regarding the model cost elements. First, the model computes life cycle cost in constant dollars. Second, the model specifically computes only those logistics support costs associated with the weapon system, subsystem and LRU indenture levels. The SRUs are derived through implicit consideration of their relationship to the repair of a given LRU. For example, average costs of SRUs are computed based on the failure rates of the LRUs.

Regarding maintenance costs, the cost model calculates costs based on a support concept driven by equipment failures in the same way that the Reliability and Maintainability Model computes maintenance resource demands. To compute the labor costs for scheduled maintenance, the maintenance events must be treated as if they were corrective maintenance actions. The reliability value can be interpreted as a function of the periodicity of the scheduled action in respect to the system operational scenario.

Criterion No. 4 - Is the cost model documentation complete and clear?

It was determined that the documentation is sufficient to exercise the model and to analyze its results.

<u>Page-Estimating Equations</u>

Programming Language: FORTRAN IV
Core Requirement: 125K
Operation: Interactive

<u>General Description</u>: These equations estimate the technical order requirements of a new system. Specifically, it estimates the number of pages and the types of pages (narrative or illustrations) for job guides,

fault isolation and general system manuals. It can also provide estimates for conventional technical manuals which are composed primarily of narrations and theory.

Data inputs are simple; the program requires the number of systems, subsystems, LRUs and SRUs in the design. The estimating relationships in this program are divided into electrical and mechanical/hydraulic categories. That is, one set of equations may be selected to generate technical order estimates for electrical systems; another set may be used for mechanical/hydraulic technical order requirements.

Radar Test Synopsis: The logistics engineers applied the electrical system equations to both configurations of the radar. Their input data consisted of the number of subsystems, LRUs, and SRUs contained in each configuration. For the baseline radar there were three subsystems, six LRUs, and 72 SRUs. For the improved radar configuration, there were three subsystems, five LRUs, and 58 SRUs.

Logistics engineers entered these data into the equation program through the interactive mode. They invoked the electrical system equations which began to process the data and to generate the estimates.

The number of conventional technical order pages to support the baseline configuration were calculated first. The conventional technical orders would be used at the organization and intermediate maintenance levels. The logistics engineers calculated 45 pages for the organizational technical manual and 531 pages for the intermediate maintenance manual. For the improved radar configuration, they estimated 39 pages and 432 pages for the organizational and intermediate maintenance manuals, respectively. Table 5 depicts the conventional manual page counts. Page content is also indicated in the table. Additionally, page content and page quantity is segregated into troubleshooting (TS) and nontroubleshooting (NTS) tasks for both the flightline and the shop.

The page estimates for the task-oriented manuals were then calculated for the baseline and improved radar configurations. The results appear in Table 6. For the baseline radar, the logistics engineers estimated 165 pages for organizational manuals and 531 pages for the intermediate maintenance manual. For the improved radar configuration, they calculated 140 pages and 432 pages, respectively.

The Assessment:

Criterion No. 1 - Can these estimating equations provide logistical information critical to the selection of one design option over another?

The logistics engineers rated the equations as marginal. The equations can provide rough estimates of the technical order page requirements a system may generate using very superficial data such as the number of components that comprise the system. This is useful during conceptual design studies; however, as the system design matures, it may be rendered grossly inadequate to provide specific techical order estimates. The following evaluations may help clarify this assessment.

Table 5. PAGES Conventional Manual Estimates

TECH MANUAL CONTENT ESTIMATE
ELECTRONICS - CONVENTIONAL

| PAGE TYPE | TS | | NTS | |
|---|---|---|---|---|
| | F/L | SHOP | F/L | SHOP |
| NARRATIVE | 12 | 39 | 18 | 129 |
| HALF TONE ART | 6 | 42 | 3 | 39 |
| HALF TONE EXPLOSION | 0 | 39 | 0 | 3 |
| ELECTRONIC LINE ART | 6 | 150 | 0 | 78 |
| EXPLODED LINE ART | 0 | 12 | 0 | 0 |
| FAULT ISOLATION CHART | 0 | 0 | 0 | 0 |
| FAULT ISOLATION SCHEMATIC BLOCK | 0 | 0 | 0 | 0 |
| ACCESS LINE ART | 0 | 0 | 0 | 0 |
| FAULT ISOLATION SCHEMATIC FLOW | 0 | 0 | 0 | 0 |
| FAULT ISOLATION SCHEMATIC MECH/H | 0 | 0 | 0 | 0 |
| | 0 | 0 | 0 | 0 |
| JOB GUIDE ILLUSTRATIONS | 0 | 0 | 0 | 0 |
| TOTAL | 24 | 282 | 21 | 249 |

| | |
|---|---|
| SUBSYSTEMS | 3. |
| LRU | 6. |
| GRU | 72. |

The Baseline Configuration

TECH MANUAL CONTENT ESTIMATE
ELECTRONICS - CONVENTIONAL

| PAGE TYPE | F/L | SHOP | F/L | SHOP |
|---|---|---|---|---|
| NARRATIVE | 11 | 32 | 15 | 105 |
| HALF TONE ART | 5 | 34 | 3 | 32 |
| HALF TONE EXPLOSION | 0 | 32 | 0 | 3 |
| ELECTRONIC LINE ART | 5 | 121 | 0 | 63 |
| EXPLODED LINE ART | 0 | 10 | 0 | 0 |
| FAULT ISOLATION CHART | 0 | 0 | 0 | 0 |
| FAULT ISOLATION SCHEMATIC BLOCK | 0 | 0 | 0 | 0 |
| ACCESS LINE ART | 0 | 0 | 0 | 0 |
| FAULT ISOLATION SCHEMATIC FLOW | 0 | 0 | 0 | 0 |
| FAULT ISOLATION SCHEMATIC MECH/ H | 0 | 0 | 0 | 0 |
| JOB GUIDE NARRATIVE | 0 | 0 | 0 | 0 |
| JOB GUIDE ILLUSTRATIONS | 0 | 0 | 0 | 0 |
| TOTALS | 21 | 229 | 18 | 203 |

| | |
|---|---|
| SUBSYSTEMS | 3. |
| LRU | 5. |
| SRU | 58. |

The Improved Configuration

Table 6. PAGES Task-Oriented Manual Estimates

TECH MANUAL CONTENT ESTIMATE
ELECTRONICS - TASK-ORIENTED

| PAGE TYPE | TS | | NTS | |
|---|---|---|---|---|
| | F/L | SHOP | F/L | SHOP |
| NARRATIVE | 9 | 39 | 0 | 129 |
| HALF TONE ART | 0 | 42 | 0 | 39 |
| HALF TONE EXPLOSION | 0 | 39 | 0 | 3 |
| ELECTRONIC LINE ART | 0 | 150 | 0 | 78 |
| EXPLODED LINE ART | 0 | 12 | 0 | 0 |
| FAULT ISOLATION CHART | 18 | 0 | 0 | 0 |
| FAULT ISOLATION SCHEMATIC BLOCK | 6 | 0 | 0 | 0 |
| ACCESS LINE ART | 12 | 0 | 0 | 0 |
| FAULT ISOLATION SCHEMATIC FLOW | 0 | 0 | 0 | 0 |
| FAULT ISOLATION SCHEMATIC MECH/ H | 0 | 0 | 0 | 0 |
| JOB GUIDE NARRATIVE | 0 | 0 | 60 | 0 |
| JOB GUIDE ILLUSTRATIONS | 0 | 0 | 60 | 0 |
| TOTAL | 45 | 282 | 120 | 249 |

SUBSYSTEMS 3.
LRU 6.
SRU 72.

Baseline Configuration

TECH MANUAL CONTENT ESTIMATE
ELECTRONICS - TASK-ORIENTED

| PAGE TYPE | TS | | NTS | |
|---|---|---|---|---|
| | F/L | SHOP | F/L | SHOP |
| NARRATIVE | 3 | 32 | 0 | 105 |
| HALF TONE ART | 0 | 34 | 0 | 32 |
| HALF TONE EXPLOSION | 0 | 32 | 0 | 3 |
| ELECTRONIC LINE ART | 0 | 121 | 0 | 63 |
| EXPLODED LINE ART | 0 | 10 | 0 | 0 |
| FAULT ISOLATION CHART | 16 | 0 | 0 | 0 |
| FAULT ISOLATION SCHEMATIC BLOCK | 6 | 0 | 0 | 0 |
| ACESS LINE ART | 10 | 0 | 0 | 0 |
| FAULT ISOLATION SCHEMATIC FLOW | 5 | 0 | 0 | 0 |
| FAULT ISOLATION SCHEMATIC MECH/H | 0 | 0 | 0 | 0 |
| | 0 | 0 | 50 | 0 |
| JOB GUIDE ILLUSTRATIONS | 0 | 0 | 50 | 0 |
| TOTALS | 40 | 229 | 100 | 203 |

SUBSYSTEMS 3.
LRU 5.
SRU 58.

Improved Configuration

Criterion No. 2 - Are the data elements well defined?

Its data elements are not well defined. Although it requires only a parts count for either an electrical or mechnical/hydraulic system, it does not define the data collection methodology. Furthermore, users must create their own definitions regarding system, subsystem, LRU, and SRU composition.

The equations can generate output within a few minutes once the data are loaded into the program. Data can be loaded manually or the Reliability and Maintainability Model data base may be accessed to run these equations.

Criterion No. 3 - Are the assumptions behind the Page Estimating Equations explicit and do they make intuitive sense to a logistics engineer?

The theoretical statement is explicit. The assumption states that equipment complexity is proportionally related to the number of technical order pages required to support a system. It is also assumed that different kinds of illustrations (e.g., line art, schematics and block diagrams) are directly correlated with equipment complexity. These assumptions have not been rigorously tested to merit any measure of confidence. Care should also be exercised if the Page Estimating Equations are applied to a variety of aircraft. Its estimating relationships were derived from tactical fighter maintenance manual data and are best suited for tactical fighter weapon system applications. Application to systems other than fighter aircraft may require reestimation of the parameter coefficients.

*Criterion No. 4 - Is the documentation complete and clear?*

The documentation is not complete in terms of a specified methodology. The documentation is not clear in terms of clearly stated results. The equations estimate total page quantities. They do not estimate page content and page quantity for a specific maintenance manual type; they force the user to aggregate the pages into the desired manual, either a job guide or a combined fault isolation and general system manual. There is no rationale to justify the latter combination. Reference 20 is the documentation source for these equations.

<u>Training/Aiding Matrix</u>

Programming Language: FORTRAN V
Core Requirement: 125K
Operation: Interactive

<u>General Description</u>: The Training/Aiding Matrix (TAM) indicates the relative emphasis that should be placed on technical training and the technical manual for proper performance of maintenance tasks assigned to a new weapon system. The matrix uses ratios of numbers consisting of 1's, 2's, and 3's to indicate whether technical training or technical manuals should be given light, medium, or heavy emphasis to support the inventory of tasks. The tasks that the matrix requires for its computations are the

troubleshooting and nontroubleshooting flightline tasks and intermediate shop repair tasks. The matrix inputs include the number of flightline and shop tasks, average task times, task frequencies, and average crew sizes. Detailed operating instructions for the matrix may be found in Reference 20.

Radar Test Synopsis: The logistics engineers used the matrix to explore the training and technical manual coverage implications for the radar's maintenance tasks. The required data came from the data base that had been compiled to run the Reliability and Maintainability Model, the Reliability and Maintainability Cost Model, and the Page-Estimating Equations.

Tables 7 and 8 present the output generated by the matrix for the baseline and improved radar configurations, respectively. The matrix displays the three basic types of maintenance tasks as column headings. The left hand margin depicts the equipment subsystems and their indigenous line replaceable units. Each radar configuration consisted of three subsystems: a mechanical one (coded AFRME), a digital (coded AFRDI), and a radio frequency (coded AFRRF). The ratios of numbers represent the emphasis to be placed on training and technical manuals for the maintenance tasks. These ratios depict the head/book tradeoffs. For example, the number "1" in the ratio "1/3" indicates light technical training emphasis for a set of maintenance tasks while the "3" indicates heavy concentration in technical manuals. The logistics engineers broadly interpreted the matrix output in Table 7. It appeared that the baseline radar would need more technical manual support for its flightline maintenance tasks than for technical training support. Shop tasks would require an even division between technical training and technical manual emphasis. Similar conclusions were drawn for the improved radar configuration's training/manual trade-offs in Table 8. It is left as an exercise for the reader to examine each training/manual trade-off for each subsystem.

The Assessment:

Criterion No. 1 - Can the matrix provide logistical information critical to the selection of one design option over another?

It could not be determined if the information derived from the matrix could be of any consequence in design option selection. The output is self-explanatory and perhaps ridiculously simple; however, the manner in which the matrix processes its inputs is vague. The matrix is supposedly the mechanism which the Integrated Task Analysis Procedure uses for coordinating the development of the technical orders and training programs.

Criterion No. 2 - Are the data elements well defined?

The data elements are not explicit. For example, the matrix requests that the user input median performance standards and decimal factors for the maintenance task inputs without further explanation. The user may provide unsubstatiable estimates which ultimately undermine the matrix outputs.

Criterion No. 3 - Are the theoretical assumptions explicitly stated and do the make intuitive sense to a logistics engineer?

Table 7. TAM Baseline Radar Assessment

TRAINING/AIDING MATRIX

| EQUIPMENT | FLIGHTLINE NONTROUBLESHOOT | FLIGHTLINE TROUBLESHOOT | SHOP REPAIR | |
|---|---|---|---|---|
| AFRRF | 2 / / 2 | 2 / / 3 | | H / / B |
| AFRRF1 | | | 2 / / 2 | |
| AFRRF2 | | | 2 / / 2 | |
| AFRD1 | 1 3 | 2 / 3 | | H / / B |
| AFRD11 | | | 2 / / 2 | |
| AFRD12 | | | 2 / / 2 | |
| AFRME | 3 / / 1 | 1 / / 3 | | H / / B |
| AFRME1 | | | 2 / / 2 | |
| AFRME2 | | | 2 / / 2 | |

Table 8. TAM Improved Radar Assessment

TRAINING/AIDING MATRIX

| EQUIPMENT | FLIGHTLINE NONTROUBLESHOOT | FLIGHTLINE TROUBLESHOOT | SHOP REPAIR | |
|---|---|---|---|---|
| AFRRF | 2 / / 2 | 2 / / 3 | | H / / B |
| AFRRF1 | | | 2 / / 2 | |
| AFRRF2 | | | 2 / / 2 | |
| AFRDI | 1 / / 3 | 2 / / 3 | | H / / B |
| AFRDIT | | | 2 / / 2 | |
| AFRME | 3 / / 1 | 1 / / 3 | | H / / B |
| AFRME1 | | | 2 / / 2 | |
| AFRME2 | | | 2 / / 2 | |

The theoretical statements are not explicit. The algorithms which process the data are not clearly evident, and therefore, the engineers could not verify or dispute the statistical nature of the training course versus technical manual trade-offs. The matrix is heavily biased toward technical order emphasis.

Criterion No. 4 – Is the documentation complete and clear?

The documentation is not clearly presented. There are ample opportunities for misunderstandings and confusion because a data element dictionary does not exist.

The Training/Aiding Matrix application ended the radar test demonstration of ASSET. The Training Requirements Analysis Model and the Personnel Availability Model were not used because of numerous technical difficulties encountered in attempts to run them. The models would have been used to evaluate the training and personnel requirements of the two radar configurations. In doing so, the logistics engineers would have evaluated both models against the four criteria. A description of their hypothesized strengths and evident technical weaknesses can be found in Reference 25.

The logistics engineers prepared a design option decision tree to summarize the supportability considerations of both radar configurations. Although the radar configuration assessments are incidental to the true purpose of the test and evaluation sequence (i.e., the ASSET package assessment) the outcome may prove interesting from an academie standpoint. Figure 8 depicts the two design options. Their reliability and maintainability figures of merit, life cycle costs, and training and technical order requirements estimates are annotated on their portions of the decision tree. Although a decision tree can be annotated with data down to the LRU, this tree depicts only the two systems and their indigenous subsystems, to minimize complexity. It appears that the improved radar configuration does not have a significant advantage over the baseline design.

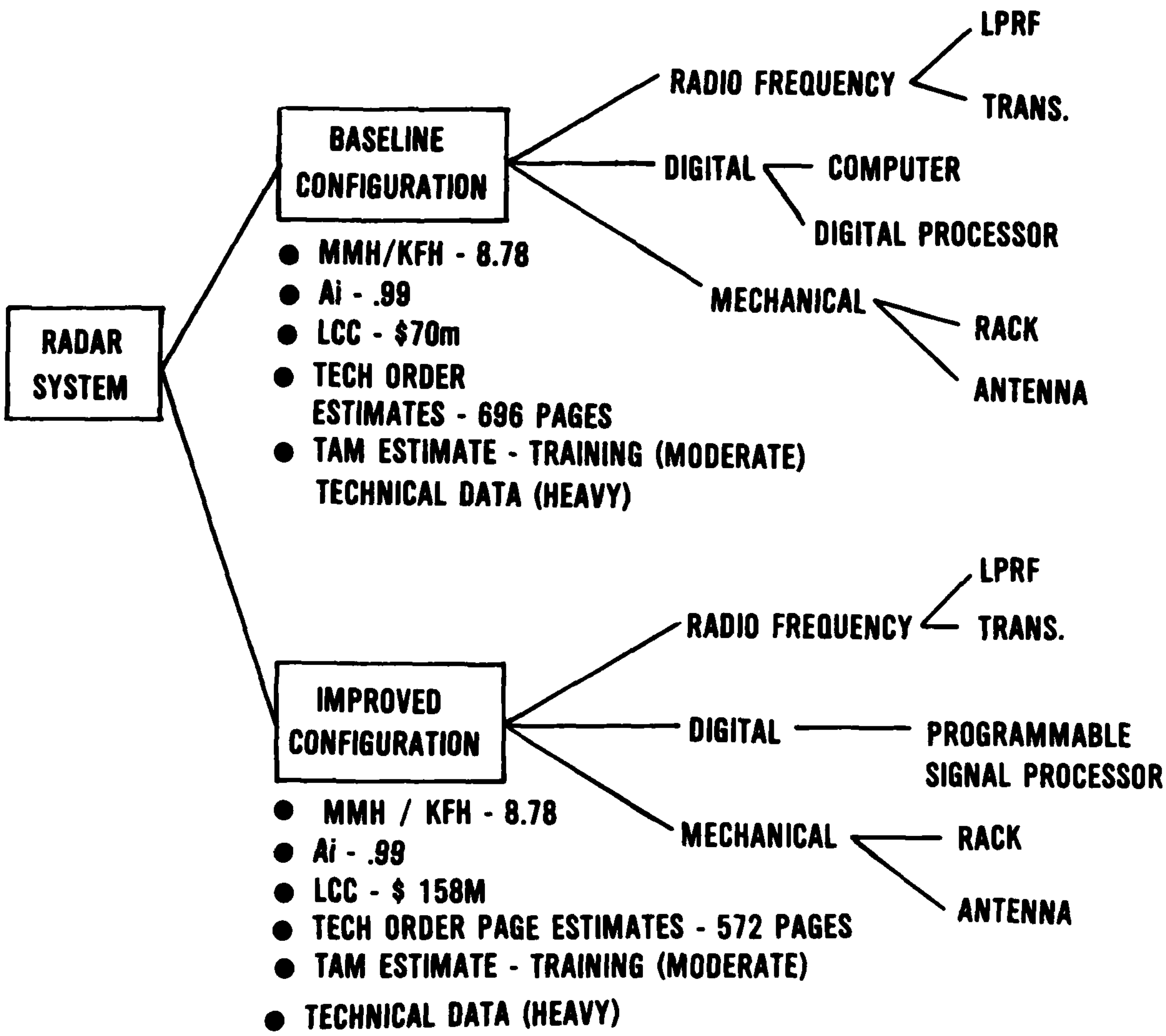



Figure 8. Resources Assessment Decision Tree for Radar Test

## 5.0 CONCLUSIONS

In summary, this test and evaluation of the ASSET technology involved a number of steps. First, the researchers established the hypothesis. The assumption was that ASSET could effect the consideration of logistics factors in weapon system design during design development. Second, an appropriate test bed was selected: a radar system. Third, evaluation criteria were devised to measure ASSET's operational readiness and efficacy. Fourth, the ASSET components were applied to the test bed. Fifth, the components were evaluated. What remains is an overall assessment of the ASSET package. Does ASSET do what it was intended to do? What procedures and tools within the package can be recommended for use?

Criterion No. 1 (rephrased): Can ASSET effect the consideration of logistics factors in weapon system design?

ASSET can indirectly effect their consideration. The results of the analytical tools may provoke inquiry and stimulate further investigation into the complex factors that impact weapon system supportability.

ASSET does not contribute a substantial amount of logistical information critical for alternative design trade off decisions because of inherent technical inadequacies which undermine the methodology and ultimately limit its credibility.

Criterion No. 2 - Is ASSET well defined?

This question addresses its procedures and tools. Only the Integrated Task Analysis Procedure, Maintenance Action Network, Consolidated Data Base Development, and Design Option Decision Tree are well defined. The user is expected to have a working knowledge of life cycle cost analysis and comparability analysis. The procedures, Program Definition Analysis, and Logistics Resources Assessment resemble processes more than procedures and, hence, contain little concrete direction.

The models in ASSET that constitute its analytical tools range from poorly defined to adequately defined in terms of the data elements and the operating assumptions. To be adequately defined means that the models can be operated and results obtained even though there may be concerns over data element definitions and operating assumptions. Poorly defined denotes significant data element and assumption obscurities. The Reliability and Maintainability Model and the Reliability and Maintainability Cost Model are adequately defined models. The Page Estimating Equations program is adequately defined but to a lesser extent because of methodological inconsistencies. Training/Aiding Matrix is poorly defined in data elements and operating assumptions. The Training Requirements Analysis Model and the Personnel Availability Model contain ill defined data elements and obscure operating assumptions.

Criterion No. 3 - Is ASSET's concept explicit? Does it make intuitive sense to a logistics engineer?

To answer the second question first: Yes, the concept does make sense. The major premise of ASSET is to consider the human resources and other logistics considerations in system design as early as possible to ensure the development of supportable and cost-effective weapon systems. Few would dispute that premise. ASSET conceptualizes how it should be applied to achieve the desired effect yet it does not describe the interrelationships that must exist within the design and logistics community to ensure that logistics factors are seriously considered and that weapon systems are developed which maximize supportability.

Criterion No. 4 - Is ASSET documentation complete and clear?

The documentation is a users manual which has information on the procedures and instructions to operate the models. The manual should be supplemented with other technical literature to obtain a full appreciation of the technology package. Supplementary materials have been identified throughout this report. A potential ASSET user can apply the ASSET components with minimal difficulty using the application manual and supplemental documentation.

## 6.0 RECOMMENDATIONS

ASSET does not provide the complete system for supportability analysis and conceptual phase design impact that was originally envisioned. However, many of the models have been refined and used by the Navy in their HARDMAN methodology. The following ASSET models and procedures can be usefully applied with adequate data to appropriate problems:

- Reliability and Maintainability Cost Model. If a user were interested in an interactive life cycle cost model for fast feedback on recurring or nonrecurring costs, it is recommended that this model be considered for potential application.

- Reliability and Maintainability Model. This model determines average maintenance times and maintenance manhours plus skill levels to be associated with a system design. Other models or techniques should be investigated for total resource requirements.

- The Design Option Decision Tree and Integrated Task Analysis. These procedures are recommended for application in developing basic maintenance data and structuring trade-off considerations.

- Page-Estimating Equations. Estimating relationships such as the Page-Estimating Equations may be used to develop technical order baselines against which contractor technical order proposals may be evaluated. If the per-page labor and material cost estimates are known, then a "should-cost" study can be prepared to use during technical order procurement negotiations. These equations were used to prepare a should cost study for the F-16 System Project Office in 1976. They were used again to prepare a baseline for the B-1 Bomber technical order management personnel in 1982. The user must take care to reestimate the equations for the specific application to fine tune their estimating accuracy and precision. An axiom may be in order here. The power of any analysis tool is derived from the quality of its data. Questionable inputs will yield only questionable results. Therefore, it is imperative that the potential user carefully review the data input requirements of each tool to determine, first, if the model can provide the answers sought and, second, if the data required are available.

If ASSET proved anything at all, it demonstrated the feasibility of conducting various kinds of analyses from reliability and maintainability evaluations to life cycle cost from a single data base that supports a weapon system design.

A number of factors that influenced ASSET's development altogether weakened its technical capabilities and may serve as lessons learned to other organizations contemplating similar ventures.

The first factor, and perhaps the most critical, was that no user was identified at the onset who had a direct interest in the R&D effort and who would be bound to apply it or any of its components when developed. Although potential users were identified because of ASSET's perceived relevance to their individual charters (e.g., Air Training Command and ASSET's training component) no specific organizations were committed to ASSET and no firm agreements were established for its use. The second factor is fallout from the first: R&D on ASSET was insulated from real-world considerations. Without close coordination with a user, a technology product may be developed that will have limited application in the real world. The Laboratory developed ASSET for use as a complete package addressing, in coordinated fashion, the training, life cycle cost, personnel and other logistics implications of weapon system development, not fully realizing that the behavioral and political content of weapon system acquisition did not lend itself well to the coordinated consideration of all those logistics factors. Furthermore, the very detailed data requirements of many ASSET models limit its applicability during the conceptual design phase unless a determined effort is made to uncover comparable data. This fact makes ASSET better suited for analyses during the full-scale development phase of system acquisition. Had a user been identified and consulted during ASSET's development, the technology package may have been configured differently for realistic applications.

The last two factors are products of hindsight. ASSET lacked and still lacks a strong data interface between its tools and popular Department of Defense analytical models. The capability for the transfusion of data between a credible model and a newly developed one that could provide either quicker responses or alternative analyses would have increased user acceptance. Lastly, no mechanism was established to update ASSET. Over time, computer programs need refinement, techniques such as regression equations must be revalidated and procedures for problem solving must be reexamined periodically to ensure their relevance to the issues that they address. Currently, ASSET components must be closely examined for their applicability to problems on a case-by-case basis.

Since ASSET involves off-line analysis, it may be considered obsolete in view of advanced manufacturing technologies, such as computer-aided design and computer-aided manufacturing (CAD/CAM), that will streamline product design and production. CAD/CAM allows the evaluation of numerous design options without prototypes. Additionally, it provides the design engineer with rapid on-line analysis capability. The ASSET package or a similar package, may be more effective if it could be integrated into CAD/CAM operations. It is believed that logistics considerations may have a better chance of influencing weapon system design within this new manufacturing technology. Future AFHRL R&D will investigate existing techniques such as those in ASSET which can be modified for access through computer-aided design terminals as a more effective means to impact system design. Such techniques might provide more timely analysis of operational support factors, such as operational readiness, life cycle cost, reliability and maintainability, than does the current method of off-line analysis and after-the-fact design review.

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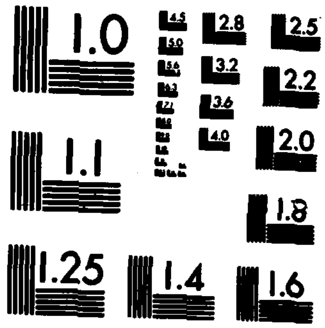


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Make the following pen and ink changes:

1. Page 14, Change last sentence at top of page from: "Consult Reference 11..." to: "Consult Reference 1..."

2. Page 14, Change last sentence in parentheses at bottom of page from: "Reference 8..." to: "Reference 14..."

3. Page 16, Change last sentence of first paragraph on page from: "In-depth descriptions of the generalized maintenance action network may be obtained from Reference 24." to: "...from Reference 9."

4. Page 20, Change last sentence of first paragraph at top of page from: "Consult References 19, 20 and 26 for guidance." to: "Consult References 19, 23, and 24 for guidance."

5. Page 20, Change last sentence in fifth paragraph from the top of the page from: "The user must refer to other sources, such as indigenous engineering personnel or References 11 and 19 for assistance." to: "...or References 23 and 24 for assistance."

6. Page 22, Change last sentence in first paragraph at top of page from: "Consult Reference 21..." to: "Consult Reference 2..."

7. Page 22, Change last two sentences in the third paragraph from the bottom from: "Detailed information regarding the Reliability and Maintainability Model may be obtained from Reference 20." to: "...Reference 10."
   "Additional sources for the Reliability and Maintainability Model are References 22 and 23." to: "An additional source for the Reliability and Maintainability Model is Reference 11."

8. Page 23, Change last sentence in fifth paragraph from top of page from: "Detailed descriptions of these reports may be obtained from Reference 20." to: "Detailed descriptions of these reports may be obtained from Reference 10."

9. Page 23, Change last sentence in third paragraph from bottom from: "A print-out from the data inputs and data values may be obtained from Reference 20." to: "...from Reference 1."

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